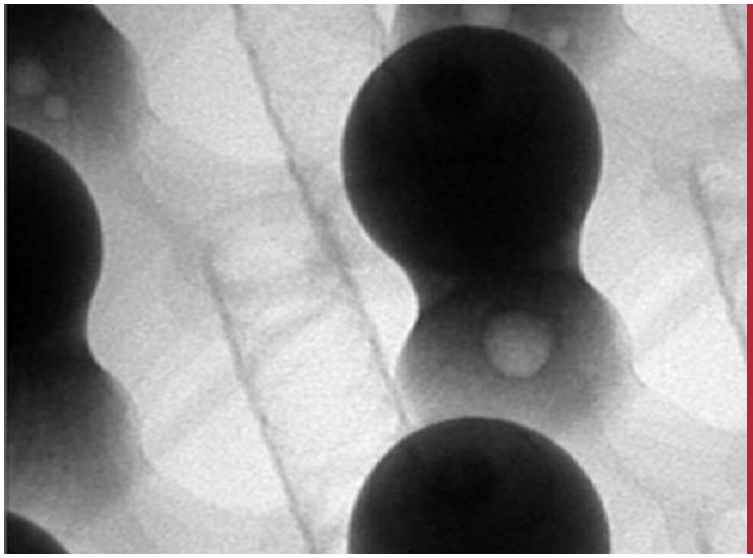


A new technology offers a different approach to x-ray inspections.

X-RAY SYSTEMS SHARPEN IMAGES

Most test engineers understand how an x-ray inspection system can examine solder joints that are hidden under a component or are too small for other inspection techniques. But they may not know that x-ray imaging technologies perform inspections in different ways, from 2-D transmission equipment that shows everything in an x-ray beam's path to 3-D systems that can eliminate visual "interference" from components on double-sided printed-circuit boards (PCBs). Although 2-D x-ray systems remain useful, 3-D systems predominate in inspection of densely packed double-sided PCBs. (See "2-D systems remain alive and well," p. 48.)

Two well-known makers of PCB test equipment also produce 3-D x-ray inspection systems for the electronics industry. At present, Agilent Technologies' 5DX series dominates the market, but Teradyne's ClearVue system is emerging as a competitor.

Agilent's 5DX family (**Figure 1**), now in its fourth generation, has gone through changes that improved its repeatability and throughput, according to Glen Leinbach, an x-ray-system expert formerly with Agilent. "The basic technology should remain useful for a long time. Hundreds of systems use it," said Leinbach.

The system's laminography technology relies on a steerable x-ray beam that moves in synchronization with a rotating image detector (**Figure 2**). Laminography refers to the 5DX instrument's capability to image a PCB in 3-mil-thick "layers" that let test engineers view solder joints clearly on either side of a PCB.

By mathematically combining many images acquired during a scan—a complete rotation of the x-ray beam and the detector—

FIGURE 1. By continuing to refine the imaging and software capabilities of its 5DX family, Agilent Technologies has dominated the 3-D x-ray inspection market for many years.

Courtesy of Agilent Technologies.

JON TITUS, CONTRIBUTING TECHNICAL EDITOR

the system obtains an image of components free from interference from other components in the x-ray beam. In this way, a 5DX system can quickly acquire images and analyze solder-joint characteristics. Test engineers can view solder joints on the top side of the board independent of the parts on the bottom, and vice versa.

"Focus is critical in a 3-D x-ray system," explained Leinbach. A 5DX system first uses the x-ray beam to detect features on a PCB so it can align the board's x and y axes. Next, it employs a laser range finder to make a topographical "map" of the board's surface. (PCBs may have some surface distortion, such as warping.) Then, the system moves the board precisely up and down (z axis) so the x-ray beam focuses on the area of interest. The surface mapping occurs automatically, but it requires an independent scan across the board.

According to Sarah Park, business-development manager for x-ray products at Agilent Technologies, the 5DX systems can handle 0201 SMT components and can resolve solder joints spaced about 8 mils (0.2 mm) apart. When it comes to voids within solder balls or joints, the 5DX systems can detect those, too.

Software passes or fails a solder joint based on a comparison of information extracted from images and characteristics preset by test engineers. Software improvements have cut programming time considerably, and test engineers find the 5DX system easy to use, emphasized Park.

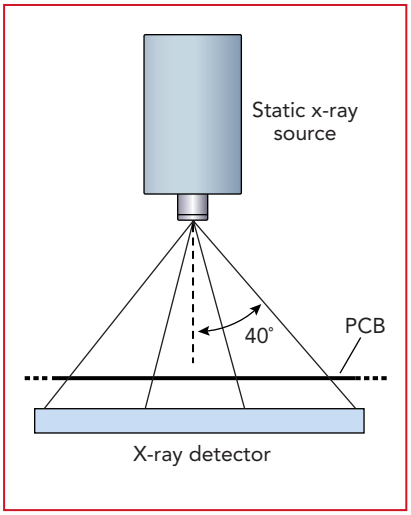


FIGURE 3. A wide-angle beam lets the ClearVue x-ray technology take off-axis images of sections of a PCB.

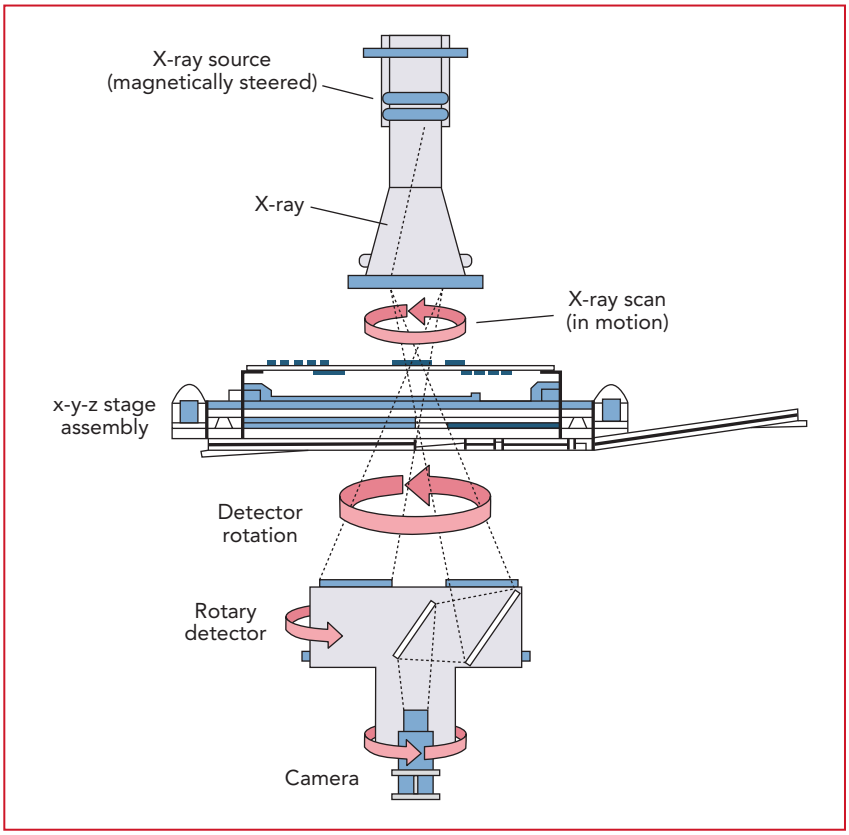


FIGURE 2. A controlled x-ray beam and a rotating detector acquire several images of an area of interest on a PCB. Software combines the images to show solder joints on only one side of a PCB.

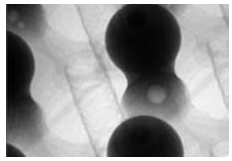
In addition to inspecting small and hidden solder joints, an x-ray inspection system provides an analytical and diagnostic tool as PCB manufacturers make the switch to lead-free solders. Greg McIntosh, product manager for the 5DX x-ray systems at Agilent, noted customers must determine how lead-free solders will affect their production processes. "Whenever you change a process, you tend to see more defects, at least early in the changeover," said McIntosh.

"When you make a major process change, you expect certain things to happen, and they usually do," explained Leinbach. "Then, the unexpected things happen and most of them are bad. The 5DX systems help you get processes back in control and back to where you had them before the change." As they switch to lead-free solders, manufacturers will use x-ray systems to help reduce reject rates and reduce the number of products that require warranty service.

An alternative approach

Although Agilent Technologies has had the 3-D x-ray inspection field mainly to itself, Teradyne, a company that already provides 2-D x-ray equipment to the electronics industry, has now entered the market. "The laminography technique is

FIGURE 4. The Teradyne XStation MX inspection equipment provides x-ray inspection capabilities built around the ClearVue technology. Courtesy of Teradyne.



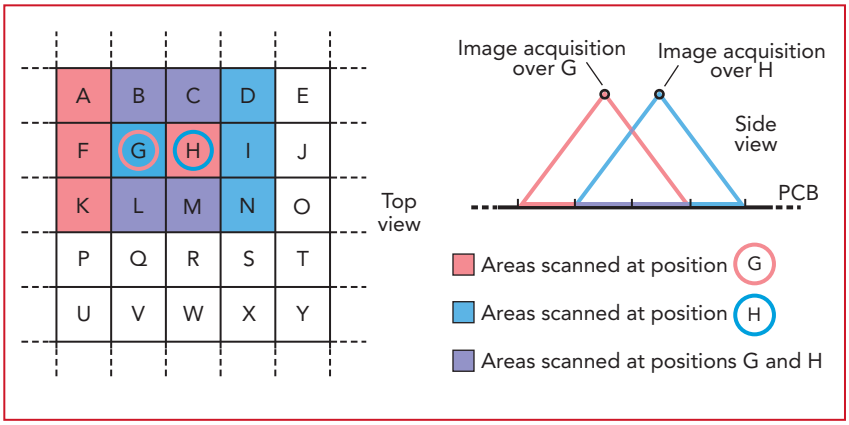


FIGURE 5. With PCB section G under the x-ray camera, the system acquires off-axis images of the red and purple sections. With PCB section H under the camera, the system acquires off-axis images of the blue areas and *different* off-axis images of the purple sections.

mechanically complex," said Paul Groome, manager of the automated x-ray inspection (AXI) products group at Teradyne. "It involves a rotating detector, a steered x-ray source, a board moving in the x-ray focal plane (z axis), and a laser topography scanner." In contrast, Teradyne's patented off-center tomosynthesis technique, called ClearVue, reconstructs 3-D slices while the x-ray source, the detector, and the PCB remain stationary. This approach to 3-D x-ray imaging inherently simplifies the inspection equipment. (The PCB moves between image acquisitions, though.)

The ClearVue technique places a wide-angle x-ray source on one side of a PCB and a large detector on the other (**Figure 3**). The x-ray beam passes through the board to the detector. But unlike a 2-D transmission system that views an x-ray beam straight through a PCB or a laminography system that employs a small angular beam, the ClearVue x-ray beam can expand to as many as 40°. Teradyne has just started to deliver its ClearVue technology in the XStation MX in-line automated inspection system (**Figure 4**).

To understand how the ClearVue technology works, imagine a PCB as a

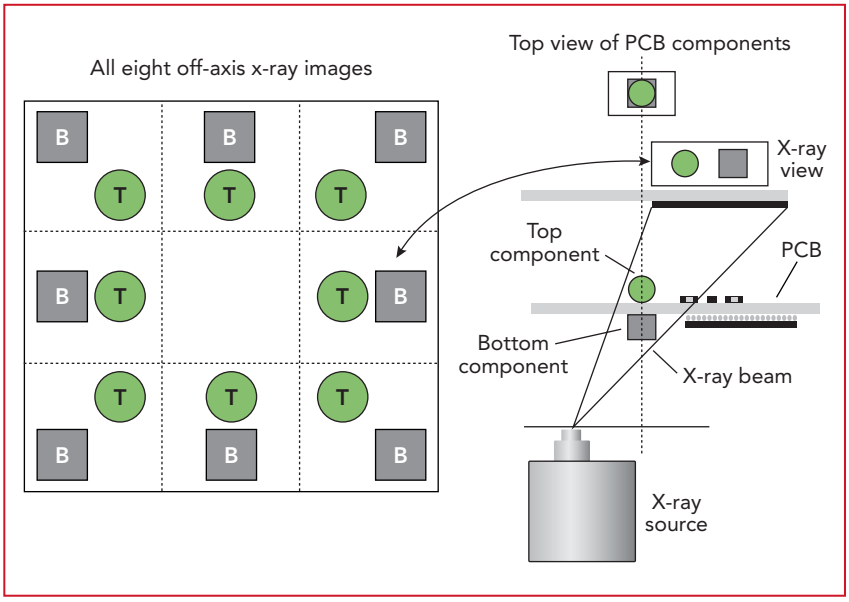
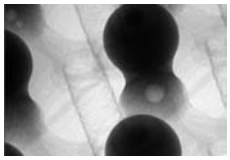


FIGURE 6. The eight off-axis x-ray images for a PCB section include all information for one section. Algorithms combine the information to let engineers selectively view components, solder joints, and other features. (Color added for emphasis.)



matrix of squares, or regions (**Figure 5**). Assume the x-ray system positions the PCB to place section G between the x-ray source and the detector. The system then can obtain off-axis, or angular, images of the surrounding eight sections, A, B, C, F, H, K, L, and M. When the system moves section H into the x-ray beam, it obtains off-axis images of sections B, C, D, G, I, L, M, and N. Note the system images sections B, C, L, and M a second time, but from different angles. Repositioning the PCB lets the x-ray system build up an array of eight off-axis images for each section (**Figure 6**). Then, a computer mathematically combines the off-axis tomographic information to construct an image of only the components in a selected plane.

FOR MORE INFORMATION

* On inspection, visit WWW.TMWORLD.COM/INS

Because the x-ray beam passes through the PCB, each set of eight off-axis images for a PCB section contains information about components on both sides of a PCB. Thus, the ClearVue algorithms can produce images of solder joints on either side. In addition, images can portray a slice through solder joints, pads, and so on, again on either side of the PCB.

The area scanned in one image can reach 2.2x2.2 in. (56x56 mm). For that size field of view, said Teradyne's Groome, equipment can inspect 6 in.^{2}/s (31 cm^2/s), about the same rate as most automated optical inspection systems. Teradyne's ClearVue technology also calculates z-axis information, so the company's 3-D x-ray equipment does not require an in-

2-D systems remain alive and well

Don Miller, president of YESTech, says companies will continue to buy and use 2-D x-ray systems for some time. In addition to inspecting PCBs on a production line, 2-D systems can provide real-time, high-resolution images of defects that 3-D systems may not resolve. "In general, hidden solder joints demand inspection by an x-ray technique, but manufacturers also may need to inspect packaged devices," stressed Miller, whose company offers 2-D x-ray systems that can resolve features as small as 1 micron.

A YESTech YTX-5000 in-line system combines automated x-ray inspection and automated optical inspection (AOI). Software provides pass/fail indications and quantitative data about solder joints.
Courtesy of YESTech.

Component densities have increased and, as a result, solder balls on IC packages such as BGAs have gotten smaller, making it more difficult to detect defects on PCBs. Thus, the high resolution of a 2-D x-ray system provides a benefit. The 2-D systems aren't perfect, though, because an x-ray image includes components on both sides of a PCB. Designers can sometimes stagger components to prevent overlap of solder pads, but small, dense PCBs may not offer that luxury.

The mandate for lead-free solders in Asia and Europe has caused apprehension among PCB manufacturers, which may lead to adoption of 2-D x-ray equipment. YESTech's Miller noted these manufacturers will use high-resolution x-ray inspections to discover the new types of soldering defects that lead-free formulations cause on their production lines.

"The lead-free alloys melt at higher temperatures, which can unduly stress ICs and components," said Miller. "So, engineers may not yet understand the types of failures and defects their processes cause. To start, PCBs and the components themselves will require the more thorough inspections that 2-D systems offer."—*Jon Titus*

dependent—and time-consuming—laser scan to map a PCB's surface. "Because the XStation MX systems don't rely on a lot of mechanical movements and because ClearVue technology doesn't average images, we can achieve false joint-defect rates below 500 joints per million solder joints inspected," said Groome.

Customers must determine how lead-free solders will affect their production processes.

At the 6-in.^{2}/s scan rate, the x-ray detector can resolve 1 mil (0.025 mm) per pixel, which lets an XStation MX system adequately view solder joints on 0201 SMT components. Because the system can adjust the angle of the x-ray beam, it can vary the field of view to examine packages such as flip chips and BGAs.

Unfortunately, Agilent Technologies' policies prevent its employees from commenting on competitive products, so Agilent's x-ray experts must remain mute about the ClearVue introduction. Still, Agilent's McIntosh noted, "The technology in this [Teradyne] introduction is new, so we know of no benchmark. Customers should ask for comparable data about throughput and accuracy. We haven't seen one of these systems or heard of a customer who has tested boards on it."

Test engineers will surely put any x-ray inspection equipment to good use. "Today, about 35 to 40% of all joints coming off a production line connect a BGA to a board," said Teradyne's Groome. "We have seen research that claims by 2007, an area-array package such as a BGA will hide about 50% of all joints produced. Many companies are already way above that percentage." T&MW